SUPERNOVA COSMOLOGY AND THE ESSENCE PROJECT

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ABSTRACT

The proper usage of Type Ia supernovae (SNe Ia) as distance indicators has revolutionized cosmology, and added a new dominant component to the energy density of the Universe, **dark energy**. Following the discovery and confirmation era, the currently ongoing SNe Ia surveys aim to determine the properties of the dark energy. ESSENCE is a five year ground-based supernova survey aimed at finding and characterizing 200 SNe Ia in the redshift domain z =[0.2−0.8]. The goal of the project is to put constraints on the equation of state parameter, w, of the dark energy with an accuracy of $\lesssim 10\%$. This paper presents these ongoing efforts in the context of the current developments in observational cosmology.

Key words: Supernovae, Cosmology.

1. INTRODUCTION

Supernova measurements have profoundly changed cosmology. The first results to argue for an accelerated rate of cosmic expansion, and thus a repulsive dark energy component, have already matured for 7 years (Riess et al., 1998; Perlmutter et al., 1999). Today these results are accommodated in what has become the concordance cosmology, flanked by constraints on the matter density, $\Omega_{\rm M}$, from large scale structure measurements, and on the flatness of space from CMB measurements. This concordance cosmology is dominated by the dark energy, $\Omega_{\rm X} \simeq 2/3$, and all present evidence is consistent with an interpretation of the dark energy as Einstein's cosmological constant, Λ (Einstein, 1917).

From the supernova cosmology perspective, the years following the 1998 discovery focused to a large extent on confirming the early results with larger and independent supernova samples, and on further investigation of potential systematic uncertainties (see e.g., Leibundgut & Sollerman, 2001; Leibundgut, 2001; Filippenko, 2004, for reviews). Within the high-z supernova search team (HZT), this effort culminated in 2003 with the analysis of over 200 Type Ia supernovae (Tonry et al., 2003). That work investigated a large number of potential pitfalls for using Type Ia supernovae in cosmology, but found none of them to be severe enough to threaten the conclusions of the 1998 paper.

With 230 SNe Ia, whereof 79 at redshifts greater than 0.3, the Tonry et al. (2003) compilation already provided interesting constraints on the dark energy. This dataset was further extended and investigated by the HZT in Barris et al. (2004) and was later also adopted by Riess et al. (2004), who added a few significant SNe Ia at higher redshifts. However, combining supernova data from a large variety of sources also raised many concerns, and it became increasingly evident that an improved at-

tack on the w-parameter (Section 2) would require a systematic and coherent survey. Most of the members in the High-z supernova search team therefore climbed the next step, into the ESSENCE project (Section 3).

2. THE EQUATION OF STATE PARAMETER

Any component of the energy density in the Universe can be parameterized using a sort of equation-of-state parameter w, relating the pressure (P) to the density (ρ) via P = w ρ c^2. This parameter characterizes how the energy density evolves with the scale factor, a; $\rho \propto a^{-3(1+w)}$. In that sense, normal pressure-less matter ($w = 0$) dilutes with the free expansion as a^{-3}, while a cosmological constant component with $w = -1$ always keeps the same energy density.

The very fact that the cosmic expansion is accelerating means that the average energy density has an equation of state parameter of $< -1/3$. The first supernova constraints on the dark energy equation of state by Garnavich et al. (1998) indicated $w < -0.6$ (95% confidence, for a flat universe with $\Omega_{\rm M} > 0.1$), and the extended analysis by Tonry et al. (2003) dictates that $-1.48 < w < -0.72$ (95% confidence for a flat Universe and a prior on $\Omega_{\rm M}$ from the 2dFGRS).

It seems that all the current supernova measurements, as well as independent ways to estimate w, are consistent with a cosmological constant, $w = -1$ (e.g., Hannestad & Mörtsell, 2004). But this is not an unproblematic conclusion. Although the modern version of Λ can be interpreted as some kind of vacuum energy (e.g., Carroll, 2001), the magnitude of the dark energy density implied by the supernova measurements is ridiculously many orders of magnitudes larger than suggested by fundamental physics. It is also difficult to understand why we happen to live in an era when Ω_Λ and $\Omega_{\rm M}$ are almost equal.

Given these objections against the cosmological constant, a variety of suggestions for new physics have emerged. Many models use evolving scalar fields, so called quintessence models (e.g., Caldwell et al., 1998), which allow a time-varying equation of state to track the matter density. In such models, the time averaged absolute value of w is likely to differ from unity. Many other models including all kind of exotica are on the market, like k-essence, domain walls, frustrated topological defects and extra dimensions. All of these, and even some versions of modified gravity models, can be parameterized using w.

An attempt to actually quantify the dark energy could therefore aim at determining w to a higher degree of precision. The project ESSENCE is designed to determine w to an accuracy of $\pm 10\%$. With that, we hope to answer one simple but important question; is the value of w consistent with -1?

3. THE ESSENCE PROJECT

The ESSENCE (Equation of State: SupErNovae trace Cosmic Expansion) project is a 5 year ground-based survey designed to detect and follow 200 SNe Ia in the redshift range $z = [0.2 - 0.8]$.

3.1. Strategy

Finding and following large batches of distant supernovae has almost become routine operation. The first heroic attempt by Norgaard-Nielsen et al. (1989) is replaced with modern wide field cameras using large CCDs and automatic pipelines for real-time object detection. As mentioned above, uniform data is required for precision measurements, and ESSENCE is therefore acquiring all photometric data with the same telescope and instrument.

Given the available telescope time, we have performed Monte Carlo simulations to optimize the constraints on w from our supernova survey (Miknaitis et al., 2003, 2006). The optimal strategy favors maximizing the area imaged, i.e., it is more efficient to monitor a large field with many SNe Ia, compared to a deeper study of a narrower field to reach a few more $z > 0.7$ SNe.

In order to reach our goal (Sect. 3.4) we will need ~ 200 well measured SNe Ia distributed evenly over the targeted redshift range. That this is a very efficient way to constrain w was shown by Huterer & Turner (2001).

In principle, the best independent supernova probe of cosmology needs to use a wide redshift distribution, in order to break the degeneracy between $\Omega_{\rm M}$ and $\Omega_{\rm X}$ (e.g., Goobar & Perlmutter, 1995). Future space-based supernova surveys will do so. But given the precise $\Omega_{\rm M}$ measurements already available within the concordance cosmology, a ground based supernova survey may exchange some of the more expensive $z > 1$ SNe with a prior on the matter density. This is how the ESSENCE project works.

The interesting aspect for a supernova project is that a sizeable effect of the equation-of-state parameter can already be seen at the moderate redshifts where a ground-based survey is feasible. In Fig. 1 we show the differences in world models calculated for different values of w. All these models have used the same cosmology ($\Omega_{\rm M} = 0.3, \Omega_{\rm X} = 0.7$, H$_0$ = 72 km s^{-1} Mpc^{-1}), and the figure shows the expected magnitude differences as compared to a $w = -1$ model. We see that there is already appreciable signal at redshifts around $z = 0.5$. This is the motivation behind the ESSENCE project.

We will populate every $\delta z = 0.1$ bin on the Hubble diagram with > 30 SNe, and thus decrease the intrinsic scatter (< 0.14 mag) to $\sim 2.5\%$ uncertainty in distance modulus. This, we believe (Sect. 3.4) is similar to our systematic uncertainties, and would, together with a $0.1(1\sigma)$ fractional uncertainty on $\Omega_{\rm M}$ provide the required accuracy of the w-determination. From the predictions in

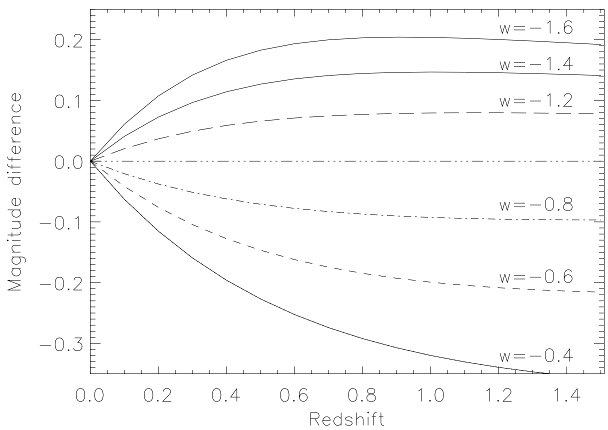

Figure 1. Predicted difference in luminosity for world models with different values for w. All models have been calculated with the same cosmological parameters ($\Omega_{\rm M}, \Omega_{\rm X}, H_0$) and are here compared to the value for the cosmological constant $w = -1$. Even at the moderate redshifts targeted in the ESSENCE project, a measureable difference in the luminosity distances is predicted.

Fig. 1 we note that at $z = 0.6$ the difference in luminosity models between $w = -1$ and $w = -1.1$ is 0.038 magnitudes.

3.2. Implementation

The work horse for the ESSENCE survey is the Blanco 4m telescope at CTIO, equipped with the Mosaic II Imager. The field-of-view for this imager is 36 × 36 arcminutes. For the 5 year duration of this endeavor, we will observe every second night during dark and dark/grey time for three consecutive months each Northern fall. We follow 32 fields that are distributed close to the celestial equator, so that they can be reached by (large) telescopes from both hemispheres. These fields were selected to have low galactic extinction, be free from very bright stars, and be located away from the galactic (and ecliptic) plane. Furthermore, the distribution in RA of the fields must allow observations at reasonable airmass over the entire semester. The total sky coverage of the search is thus 11.5 square-arcminutes. The main part of the programme is to image each field in the R and I filter bands every 4 nights. This cadence allows us to detect the supernovae well before maximum light, and to simultaneously monitor the supernovae with enough sampling for accurate light-curve fits (see e.g., Krisciunas et al., 2005).

The pipeline automatically reduces the data and performs image subtraction. The software also rejects many artefacts, such as cosmic rays, as well as asteroids and UFOs. All remaining identified variable objects are potential SNe Ia, and are prioritized based on a rather complex set of selection criteria (Matheson et al., 2005). Spectroscopy is secured on the 8m class telescopes, such as the ESO VLT, Gemini, Magellan and the KECK telescopes. These spectra are used to (i) determine the redshift required to put the object onto the Hubble diagram, (ii) ensure that the object is a SN Ia, (iii) allow detailed comparisons between low-z and high-z supernova to look for evolution (e.g., Blondin et al., 2006) and sometimes (iv) to derive an age estimate for the supernovae by comparison to local SN spectra.

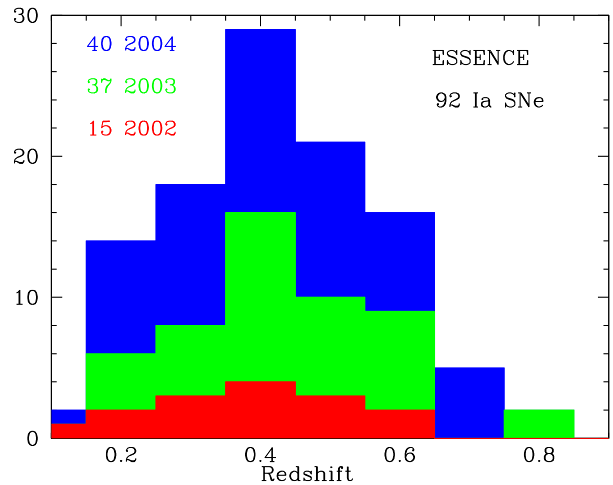

Figure 2. The redshift distribution for the SNe Ia discovered by the ESSENCE project in the first 3 years.

It should be emphasized that the usage of 8m telescopes has substantially improved the quality of the high-z supernova spectra (Leibundgut & Sollerman, 2001; Matheson et al., 2005) as compared to the SNe Ia used for the original 1998-claims.

Apart from the core-programme, the ESSENCE team and its members also embark on many complementary programmes to assess specific scientific issues related to the ESSENCE scientific goals. We have used the HST to study in detail several of the highest redshift SNe Ia in the ESSENCE sample (Krisciunas et al., 2005) and have been allocated SPITZER observing time to study a small sub-sample of ESSENCE SNe also in the rest-frame K-band, where dust and evolution are likely to be less important. There are also ongoing investigations to study e.g., ESSENCE host galaxies, time-dilation from ESSENCE spectra, and reddening constraints from additional Z-band imaging.

3.3. Current status - three out of five seasons

We have now (summer 2005) finished three of the projected five years of the survey. We have detected about 100 SNe Ia (Fig. 2). All variable objects that we discover are immediately announced on the web[1], and

[1] http://www.ctio.noao.edu/∼wsne/index.html

the supernovae discovered by ESSENCE are announced in IAU circulars (Challis, 2002; Miknaitis et al., 2002; Smith et al., 2002; Challis, 2003; Covarrubias, 2003; Covarrubias et al., 2003; Foley & Wood-Vasey, 2004; Hicken, 2004; Blondin & Prieto, 2005). We emphasize that all the images taken by the ESSENCE project are made public without further notice. Any researchers who could utilize such a uniform dataset for variable objects are welcome to do so.

The first ESSENCE paper described the spectroscopic part of the campaign (Matheson et al., 2005), and we have also discussed the properties of these spectra as compared to low-z supernovae (Blondin et al., 2006) based on a newly developed optimal extraction method (Blondin et al., 2005). The photometry for the nine supernovae monitored as part of our HST project has also been published (Krisciunas et al., 2005).

Overall, the project progresses as planned. The first season had a too low discovery rate of SNe Ia. This was largely due to bad weather, but we have also been able to improve the supernova finding software and to sharpen our selection criteria for spectroscopic follow-up, which means that the rates are now on track for the goal of 200 SNe Ia (Fig. 2).

Much of the work within the ESSENCE project has to date been put on securing the observations and constructing the real-time data analysis system. At the moment, most of the efforts are put into the investigation of the systematic errors. Different sub-groups of the team are working on e.g.;

(i) Photometric zero-point corrections

(ii) Redshift errors (from SN templates)

(iii) K-corrections (local spectral catalogue)

(iv) Light curve shape corrections (different methods)

(v) Extinction law variations and Galactic extinction uncertainties

(vi) Selection effects, including Malmqvist Bias (Krisciunas et al., 2005).

It is also important to understand exactly how these different sources of uncertainties interact. They are clearly strongly correlated, and a robust error analysis technique that contains all these steps is required. Krisciunas et al. (2005) showed that light curve fits using three different methods were consistent with each other (their tables 4,5,6). But this comparison also showed some rather large differences for individual supernovae, which may require further investigation.

3.4. Projected goal

The aim of the project is to determine w to $\pm 0.1(1\sigma)$. This is to be done by populating the Hubble diagram with a set of well observed SNe Ia in the redshift domain where we can probe the onset of the cosmic acceleration. This test is designed to examine whether or not this onset is consistent with the equation of state parameter of the cosmological constant. While it is of course of interest to also probe the time-evolution of a cosmological constant, this is very likely beyond the scope for the ESSENCE survey. Our constraints will thus be for the time-averaged value of w.

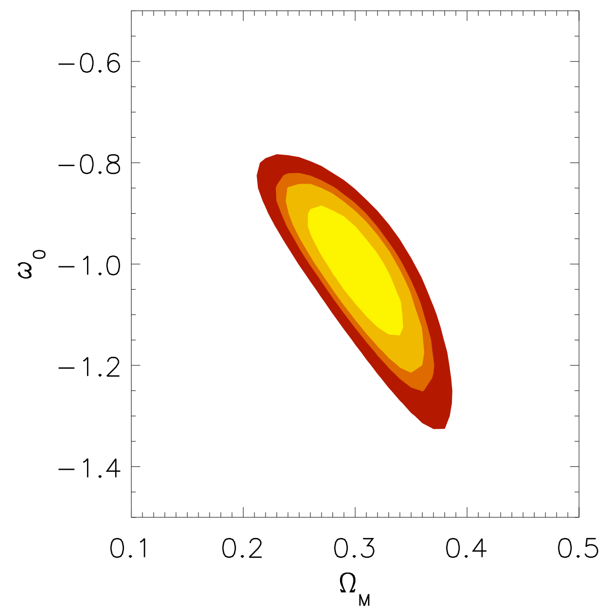

Figure 3. Predicted constraints from future supernova studies from Mörtsell & Sollerman (2005). These constraints are for 300 local SNe, the 157 gold supernovae and for 200 ESSENCE supernovae. In this plot we have also adopted a prior of $\Omega_{\rm M} = 0.3 \pm 0.03$. A flat universe with a constant w-parameter is assumed.

To be able to constrain the equation of state parameter w to better than $\pm 10\%$, we estimate that we need 200 SNe Ia to populate the Hubble diagram. How good the constraints will actually be will also depend on the adopted priors from other investigations.

For example, Mörtsell & Sollerman (2005) simulated the usage of 200 SNe with an intrinsic distance error of 0.14 mag, and distributed them over the anticipated ESSENCE redshift interval. We also added the 157 gold supernovae from Riess et al. (2004) as well as 300 local supernovae, as will be delivered by the SN factory (Aldering et al., 2002) or by the many other supernova searches conducted today, many of them including ESSENCE members (e.g., Li et al., 2003; Krisciunas et al., 2004; Jha et al., 2005).

The anticipated constrains from this simulation are displayed in Fig. 3. If we furthermore adopt a conservative prior on $\Omega_{\rm M}$ of 10% we obtain a formal 1σ error on a w determination of $6 - 7\%$. This is as good as it gets.

The constraints will also depend on the systematic errors. These are more difficult to estimate, in particular prior to the actual experiment. It is likely that the battle with the systematics will be the most important one in this supernova survey. Many of the identified systematic uncertainties were listed in Sect. 3.3 and our pre-experiment estimates of the systematic floor is at the $2-3\%$ level. Thus, the survey is designed to reach the break-even point between systematic and statistical errors.

It can be of interest to compare the above-mentioned numbers with the other ambitious SNe Ia survey presently ongoing. The CFHT Supernova Legacy Survey (SNLS, Pain et al. 2003 and these proceedings) aims to detect over 700 SNe Ia over the project lifetime. This is a substantial effort - not the least on the spectroscopic resources - where copious amounts of 8m class telescope time are required to identify all the candidates.

The first preliminary reports from the SNLS, based on the first year data only, appears to be very encouraging (Pain et al. 2006 these proceedings). Their error bar on w is already as good as $10-11\%$ (RMS), including a systematic uncertainty of about half that amount. This is based on about 70 high-z supernovae. If we assume that increasing the sample to 200 SNe will decrease the statistical noise by the Poisson contribution, the statistical error will become exactly equal to the quoted systematic error and the RMS error will be decreased to $\lesssim 0.08$. But increasing the sample up to 700 supernovae would only extrapolate to an improvement to $\simeq 0.06$ in the combined error.

That the floor of the systematic error is likely to limit the experiment rather than the number of supernovae was the main consideration in limiting the ESSENCE survey to 200 SNe. To what extent the systematics can actually be better controlled, with or without a larger sample, will therefore determine the success of these surveys.

4. CAVEATS

Any supernova cosmology review will have to carefully mention the potential pitfalls in this game, including extinction, gravitational lensing, supernova evolution coupled to metallicity or other population effects as well as selection biases. Here we briefly mention the most obvious of these.

4.1. Extinction

Dimming by dust is always present in astronomy, although there is little evidence that this is severely affecting the SNe Ia cosmology (Riess et al., 1998). Sullivan et al. (2003) showed that the dark energy dominated cosmology persists even if only supernovae in elliptical galaxies are used, excluding strong bias due to local dust. Even models of grey intergalactic dust have been proposed, but seem to have fallen out of fashion.

4.2. Luminosity Evolution

Luminosity evolution was historically the major caveat in pinning down the deceleration parameter using e.g., (first-ranked) galaxies as standard candles. It is at least clear the SNe Ia do an enormously better job as standard(izable) candles. Empirically, many investigations have searched for luminosity differences depending on host galaxy type and redshift, but after light curve shape corrections no such differences have (yet) been found (see e.g., Filippenko, 2004; Gallagher et al., 2005, and references therein).

In this respect we would of course feel much more confident if the theoretical backing of the SNe Ia phenomenon could further support the lack of evolution with redshift and/or metallicity.

The general text-book scenario for a SN Ia explosion is quite accepted; a degenerate carbon-oxygen white dwarf accreting matter by a companion star until it reaches the Chandrasekhar limit and explodes (at least initially) via deflagration. This thermonuclear blast completely disrupts the white dwarf, and converts a significant fraction of the mass to radioactive ^{56}Ni, which powers the optical light curve. But it is possible to take a more cautious viewpoint, since we have still not observed a single SN Ia progenitor white dwarf before it exploded, and in particular the nature of the companion star is hitherto unknown. It is quite possible that a multitude of progenitor system channels exists, and the redshift distributions of such populations are not known. Studies to detect and constrain the progenitor systems are ongoing, by e.g., investigating the present white dwarf binary population (Napiwotzki et al., 2002) and by searching for circumstellar material at the explosion sites (e.g., Mattila et al., 2005).

Also the explosion models have developed significantly in recent years. Röpke et al. (2005, these proceedings) present exploding 3D-models based on reasonable deflagration physics. But it is important to go beyond the simplest observables, the fact that the simulations should indeed explode with a decent amount of bang, and to compare the explosion models to real SNe Ia observations. An important step in this direction was made by Kozma et al. (2005) who modeled also the nucleosynthesis and the late spectral synthesis for comparison to optically thin nebular SNe Ia spectra. This initial attempt revealed the explosion models to produce far too much central oxygen, thus showing that efficient constraints can be directly put on the explosion models from properly selected observables. Hopefully, explosion models will soon converge to the state where it becomes possible to test to what extent a change in pre-explosion conditions - as may be suspected by altering metallicity or progenitor populations - will indeed affect the SNe Ia as standard candles.

An empirical way to investigate any potential redshift evolution is to compare the observables of the low redshift sample with those of the high redshift sample.

The most detailed information is certainly available in the spectra, and Blondin et al. (2006) have used the ESSENCE spectra for such a detailed comparison. The main conclusion of that investigation is that no significant differences in line profile morphologies between the local and distant samples could be detected.

4.3. Gravitational Lensing

Gravitational lensing is also a potential concern. Present studies indicates that the effects are small at the redshift ranges populated by the ESSENCE supernovae, but that corrections could be made for higher redshift domains, as may be reached by JDEM/SNAP (Gunnarsson et al., 2006; Jönsson et al., 2006).

Jönsson et al. (2006) recently modeled the lensing effect of 14 high-z SNe in the gold sample. The original 157 SNe in that sample (Riess et al., 2004) gives $\Omega_{\rm M} = 0.32^{+0.04}_{-0.05}\,(1\sigma)$ in a flat universe. If corrected for the foreground lensing as estimated by Jönsson et al. (2006), the constraints instead becomes $\Omega_{\rm M} = 0.30^{+0.06}_{-0.04}\,(1\sigma)$ in a flat universe. This difference is indeed very small. There is no significant correlation between the magnification corrections and the residuals in the supernova Hubble diagram for the concordance cosmology.

4.4. Selection Bias

The selection of the SNe Ia followed by ESSENCE is far from homogeneous (Matheson et al., 2005). To decide which objects are most likely young SNe Ia candidates in the targeted redshift domain, and also suitable for spectroscopic identification and redshift determination, involves a complicated set of selection criteria. The final list also depends on the availability of spectroscopic telescope time. This may mean that the selection of the distant sample is different from the nearby, for example by favoring SNe placed far from the host galaxy nucleus.

An argument against severe effects from such a bias in the distant sample is that also the nearby SNe Ia population - which is indeed shown to be excellent standard candles - is drawn from a large variety of host galaxies and environments. There is therefore reason to believe that, as long as the physics is the same, the methods to correct for the reddening and light curve shape also holds for the high-z sample (e.g., Filippenko, 2004). In fact, in terms of cosmological evolution, the galaxies at $z \sim 0.5$, where the supernova dark energy signal is strongest, have not evolved much.

In Krisciunas et al. (2005) we show that in the high-z tail of the ESSENCE redshift distribution, we are susceptible for Malmqvist bias. This is the sample selected for follow-up with the Hubble Space Telescope. However, most of our survey is deep enough to be immune to this effect. Since we do need the light curve corrections all our supernovae have to be easily detected at maximum.

4.5. Caveats - current status

The above subsections have focused on the systematic uncertainties of the supernovae as standard candles throughout the universe. After the observations of $z \gtrsim 1$ SNe, first hinted by Tonry et al. (2003), but clearly detected by Riess et al. (2004), much of the old worries about these uncertainties have disappeared. That the very distant supernovae are *brighter* than expected in a coasting universe, while the $z \sim 0.5$ SNe are *fainter* than expected, is a tell-tale signal that rules out most reasonable dust or evolution scenarios. For sure, these kind of models can still logically be constructed - but must generally be regarded as contrived.

While the conclusions from all investigations hitherto conducted give reasonable confidence that none of the known caveats (alone) are serious enough to alter any of the published conclusions, the ongoing large surveys, and in particular any future space based missions, still have to seriously investigate these effects. Clearly, the ESSENCE sample of well measured SNe Ia will make many of the requested tests for systematic effects possible to a much higher degree than hitherto possible.

5. DISCUSSION

Astronomers coming from the supernova field always stress the importance of understanding the physics of the supernovae, if not only to underpin the current cosmological claims, but also to enable future precision cosmology using SNe Ia.

Major efforts are also presently undertaken to pursue such research on supernova physics, for example within the EU Research and Training Network[2]. Having said this, it is important to make clear that SNe Ia are, in fact, extraordinary accurate as standard candles. While supernova astronomers worry about the details, other cosmologist today are enthusiastically creative with suggestions on how to observationally determine w, using gamma-ray bursts (GRB), black hole gravitational wave infall, quasar absorption line studies, GRB afterglow characteristics, all kinds of gravitational lensing, and more. Some of these suggestions are likely to complement ongoing and future supernova surveys. Most will probably not.

Particular interest was raised concerning gamma-ray bursts, following the discovery of the Ghirlanda-relation (Ghirlanda et al., 2004). There are several aspects of gamma-ray bursts that immediately make them very interesting *if* they prove possible to properly calibrate: They are extremely bright, we know that they exist also at very high redshifts, and the gamma-ray properties are not affected by intervening dust. This has raised a flurry of investigations and recently even a suggestion for a dedicated GRB-cosmology dark energy satellite (Lamb et al.,

[2] www.mpa-garching.mpg.de/∼rtn/.

2005). However, it may well be that the redshift distribution of GRBs is not as optimal as is the case for SNe Ia. In Mörtsell & Sollerman (2005) we showed that the GRB cosmology is mainly sensitive to the matter density probed at higher redshifts, and not efficient in constraining the properties of the dark energy.

SNe Ia are indeed exceptionally good standard candle candidates. They are bright and show a small dispersion in the Hubble diagram. Seen the other way around, it is SNe Ia that provide the best evidence for a linear Hubble expansion in the local universe (see e.g., Leibundgut & Tammann, 1990; Riess et al., 1996). Despite the worries voiced above, the theoretical understanding of SNe Ia is considerable, and much better than can be claimed for e.g., gamma-ray bursts. The redshift distribution of SNe Ia is also very favorable for investigations of the dark energy, and the local sample is important to tie the high-z sample to the Hubble diagram. Moreover, the local supernova sample makes it possible to understand these phenomena in detail, and to directly compare them in different environs.

5.1. Epilogue

When the acceleration of the cosmic expansion was first claimed 7 years ago, it was certainly strengthened by the fact that two independent international teams (Schmidt et al., 1998; Perlmutter et al., 1999) reached the same conclusions. The ESSENCE project, as a continuation of the HZT efforts, is today working within the concordance cosmology paradigm. But even if a detection of new physics, in the form of a $w \neq -1$ measurement, may not be as large a shock for the already perplexed physics community as the initial $\Omega_{\rm X} > 0$ result, it is likely that the competition with the SNLS will prove healthy also this time. And after all, a result where $w < -1$ is still not ruled out.

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